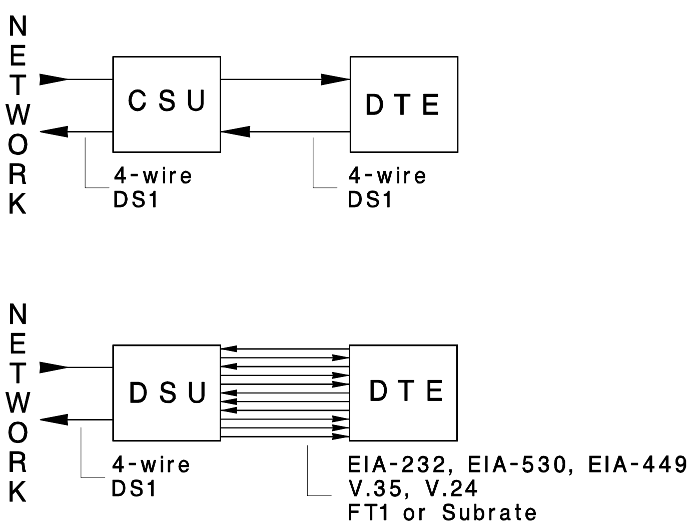
Application Note No. 3

CSU/DSU Applications in DS1 Service

1. Introduction

This application note discusses a number of the issues associated with installing a Channel Service Unit (CSU) or Data Service Unit (DSU) on a customer's premises. Fig. 1 shows the fundamental difference between the CSU and DSU. This note only discusses the simple 4-wire Data Terminal Equipment (DTE) interfaces found on CSUs and does not discuss the more complicated DTE found on DSUs. The DTE typically used with CSUs are PBXs, channel banks, and DS1 network access multiplexers. The DTE used with DSUs are subrate and Fractional T1 multiplexers, and local area network (LAN) routers and bridges.

Fig. 1
Difference Between CSU and DSU



The documentation that comes with most CSU/DSUs usually only lists the setup options and provides no guidance whatsoever on which way those options should be set for a particular application. This application note is written to fill the gap between the sparse and inadequate documentation supplied by most manufacturers and actual applications. Some CSU/DSUs interface with the DSX-1 panel, so the reader is referred to another related application note that discusses DSX applications.[1] Finally, this application note only discusses testing in the context of the CSU or DSU. A more general discussion of DS1 rate service testing can be found in yet another application note.[2]

Typical applications of a CSU and DSU, and their relationship to the network interface (NI) and DTE interfaces, are shown in Fig. 2. The CSU in this illustration is used to connect a user's PBX at location A to a digital trunk interface (DTI, also called a T1 interface) in an end office switching system. The DTE interface at the PBX is similar to the end office DTI. The DSUs in this illustration are used to connect a local area network (LAN) at location A to a LAN at location B. The DTE interface at A is V.35 and at B is EAI-449.

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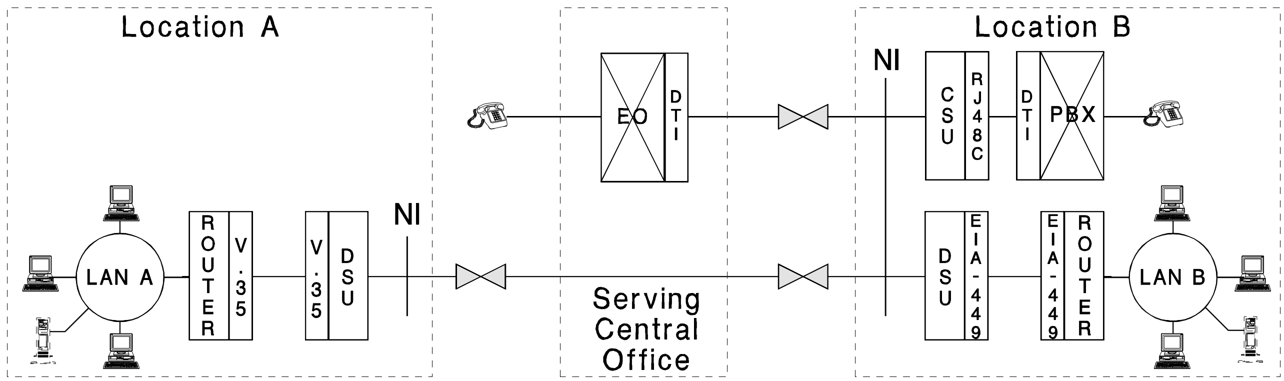
1 See Application Note No. 2, *DSX Applications in Small Central Offices.*
2 See Application Note No. 4, *Testing DS1 Services.*

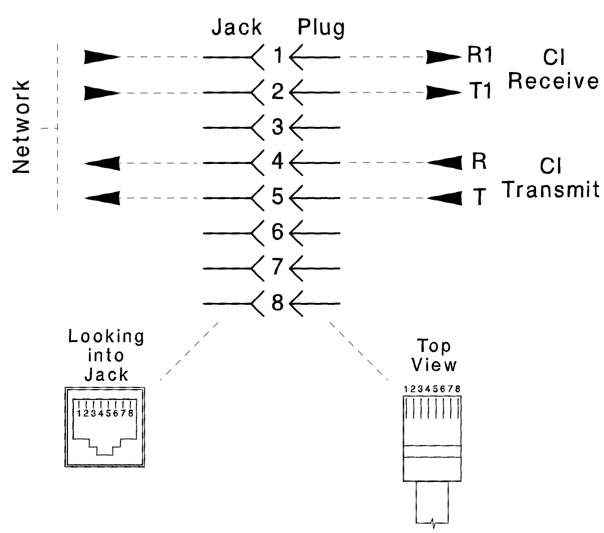
Fig. 2
CSU and DSU Application



2. Standards

ANSI T1.403 gives the electrical requirements for interconnecting customer equipment with public network DS1 services. ATIS (formerly ECSA) Report No. 5 provides connector wiring configurations.

Fig. 3
RJ48C Wiring Configuration



3. Network Interface

The network interface for DS1 service at a Customer Installation, or CI,[3] usually is a modular jack using the RJ48C wiring configuration shown in Fig. 3. This and other standard wiring configurations are described in FCC Part 68 and in industry standards including ATIS (formerly ECSA) Report No. 5. Also, the DB15 connector or *any non-discriminatory wiring method or connection* may be used by the telco at the network interface. This includes a DSX-1 interface, screw-down terminal blocks, or insulation displacement connectors (punch-down blocks). In most situations, it is advantageous to the telco to install what is usually called a "Smartjack" at the network interface, which includes loopback capability in addition to the modular jack.

FCC Part 68 requires that customer-owned digital equipment connected to the network interface provide dc isolation, voltage limitation, and transmitted signal power adjustment. The CSU and DSU provide these and other functions for DS1 services. Normally, a CSU has DS1 ports on both the network side and user, or DTE, side. When the functions of a standard interface (such as EIA-232, EIA-530, EIA-449 or V.35) are combined with the CSU, the device is called a DSU. Manufacturer's marketing campaigns frequently blur the distinction between the CSU and DSU.

[3] Customer Installation, or CI, is the terminology used in ANSI standards.

In addition to the FCC requirements, most CSUs and DSUs provide other features and capabilities, including loopback, line code options, framing format options, timing options, DTE interface options including multiple ports and multiplexing capability, and performance monitoring interfaces.

Where individual DS1 service is installed, the network interface jack uses a single RJ48C jack, which has the wiring configuration shown in Fig. 3. Individual service also may be provided through the DB15 connector. For installations that use the DB15 connector, the network interface usually has a female connector (DB15F) and the connecting cable has a male connector (DB15M). Fig. 4 shows the relationship between the pinouts of the RJ48C and DB15 connectors as they relate to the network interface, CSU and 4-wire DTE interface.

Fig. 4
DB15 and RJ48C Pinouts

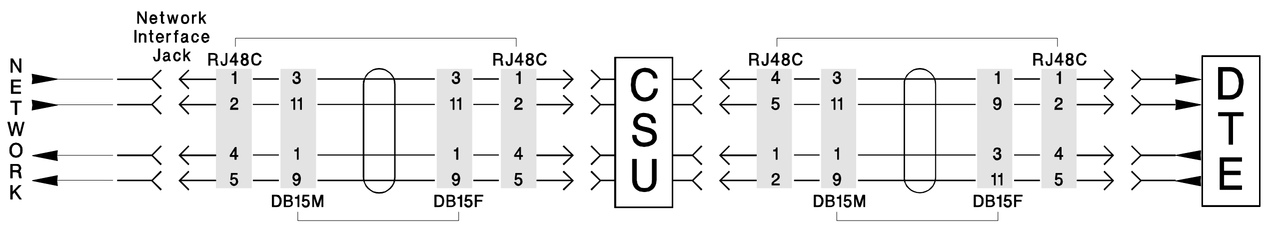
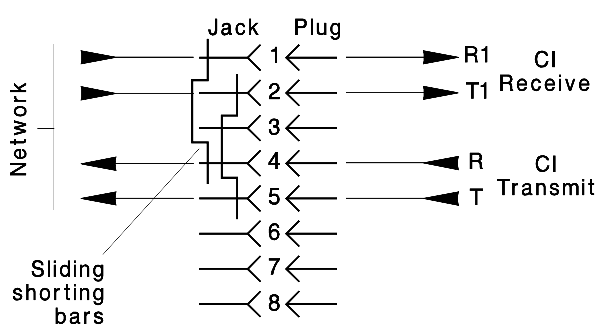


Fig. 5
RJ48X Wiring Configuration



It may be desirable in some applications to provide the RJ48X at the network interface. See Fig. 5. This jack provides automatic looping between pins 1 and 4 and between pins 2 and 5 when the customer equipment is unplugged, thus looping the receive to transmit. The looping ensures dc continuity for sealing current or line powering current, if used, and also loops the signal. However, the mechanical aspects of the RJ48X jack introduce potential reliability problems and the jack is seldom used.

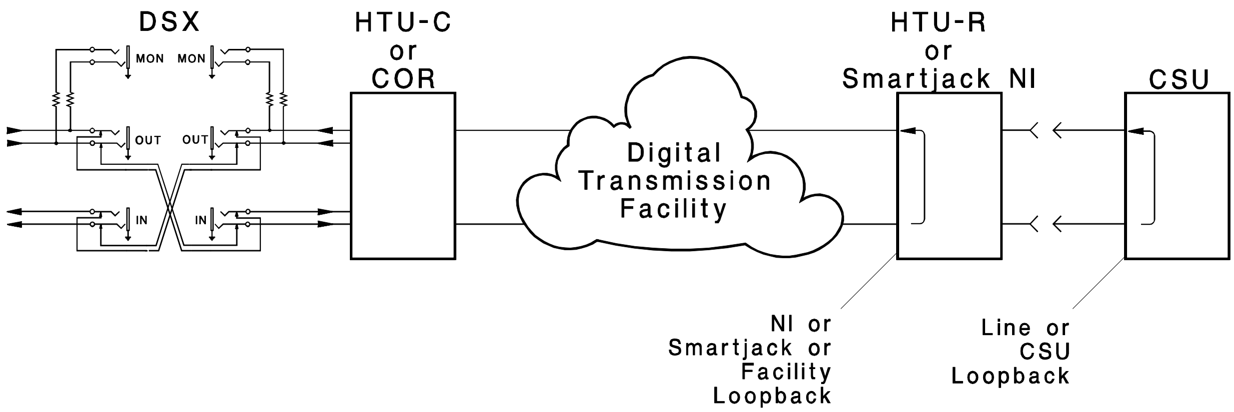
4. Loopbacks

All CSU/DSUs have internal loopbacks, and these are important test features. The signal into the CSU/DSU from the facility can be at a low level (due to loss between the first network element and the network interface), so this signal must be regenerated before it is applied to the transmit out side of the CSU/DSU.

Care must be taken to differentiate “facility” and “line” loopback. Facility loopback also is called Network Interface (NI) loopback or “Smartjack.” Line loopback also is called CSU loopback. The difference is the location of the loopback. The Facility loopback tests only the facility side of the network interface. The Line loopback tests include the facility, network interface and CSU/DSU circuitry. CSUs and DSUs usually have additional loopbacks to loop the DTE side back to the user.

The facility and line loopbacks are illustrated in Fig. 6. In this illustration, DS1 service is provided from an end office to a CSU on the customer premises. The digital transmission facility is either repeatered T1-carrier or HDSL. With repeatered T1-carrier, the facility loopback is provided in a Smartjack network interface on the customer's premises. With HDSL, the Smartjack function is provided in the HDSL remote terminal (HTU-R).

Fig. 6
Loopbacks



The most common loop-up and loop-down codes are shown in Table 1. These are not the only ones that may be encountered in the field. For example, Fractional T1 (FT1) services use repeated in-band codes for channel loopback that are significantly different than the codes described here. The reader is referred to ANSI T1.403 for additional information.

Table 1
Common Loopback Codes

Loopback Type	**Loop-Up**		**Loop-Down**	
	In-band	Out-of-band	In-band	Out-of-band
Line (CSU)	10000	0000 1110	100	0011 1000
Facility (NI)	11000	0001 0010	11100	0010 0100

The in-band codes for DS1 loopback shown in the table are sent as repeating bit sequences, which replace the payload bits in systems that use the Superframe Format (SF, also called D3/D4). The out-of-band codes are sent as repeating bit sequences in the Extended Superframe Format (ESF) facility data link and, by themselves, do not affect the payload. However, most test sets also send the in-band codes at the same time as the out-of-band codes with ESF.

Generally, it is not necessary to know the exact loopback code or bit sequence because these are pre-programmed in all modern test sets. It is only necessary to identify the type of loopback to be activated (line or facility). However, some test sets provide two options for sending the loopback code:

- *Imbedding* the loopback code in the payload of a framed sequence of bits. With this option, the loopback bits replace the payload bits. The loopback sequence is interrupted by the framing bit after 192 loopback bits and resumes after the framing bit (193rd bit) is inserted.
- *Overwriting* the loopback code with framing bits. With this option, the loopback bits are sent as a continuous sequence with framing bits overwriting the loopback sequence at the regular frame bit positions. This option is the one most commonly used.

Loop-up and loop-down codes are required to be sent for at least 5 seconds before they are acted upon by the looping device. When activated, the facility loopback (for example, in the Smartjack or HDSL remote terminal in Fig. 6) returns the signal to the sending end. At this point, any valid test signal may be used. The returned signal should meet the performance requirements for the line being tested.

When tests are completed, the loopback is deactivated by sending the appropriate loop-down code. Most CSUs and DSUs also have an option to automatically deactivate the loopback after a preset timeout period (typically 10 or 20 minutes). The timeout feature is handy to prevent extended lockup of the loopback in the event of line trouble. However, the timeout must be disabled for long-term tests.

To test beyond the facility loopback, the line loopback in the CSU is activated by sending the appropriate loop-up code. As before, any valid test signal may be used, and the returned signal should meet the performance requirements.

Valid test signals may be a quasi-random signal source, other pseudo-random bit sequences of various lengths, and stress patterns with varying numbers of zeros. Examples of invalid test signals are all-ones (also called Alarm Indicating Signal, or AIS) and signals that mimic loop-down bit sequences. Different equipment in the transmission chain may react to the AIS in different or unpredictable ways. For obvious reasons, the loop-down code or mimic codes should not be sent until the loopback is to be deactivated.

5. Test Harnesses

Some CSUs and DSUs have test jacks, which may be used to connect a test set directly to the CSU. Many devices do not have test jacks, however, so it is necessary to use a locally fabricated test harness as shown in Fig. 7. This test harness has a standard 8-position modular plug on one end and bantam plugs on the other, one for the transmit and one for the receive direction. The modular plug end of the test harness may be connected to the RJ48C jack on the back of the CSU or DSU, for testing the device as shown in Fig. 8(a), or to the network interface jack for testing toward the network as shown in Fig. 8(b). Notice that the signal direction is reversed at the network interface compared to the CSU connector.

6. Timing

When connecting and testing a DSU, care must be taken to choose the proper timing (clock) source. For example, Fig. 9 shows the timing details for the system in Fig. 1. The DS1 interfaces are routed through the telco’s serving central office. In this example, the DSU at Location A provides the timing source for the asynchronous link to Location B. It is necessary to set the DSU at Location B to obtain timing from the network and return that timing back to the network (loop-timing). The DSU passes the received timing through to the DTE.

Fig. 7
CSU Test Harness with RJ48C Connector

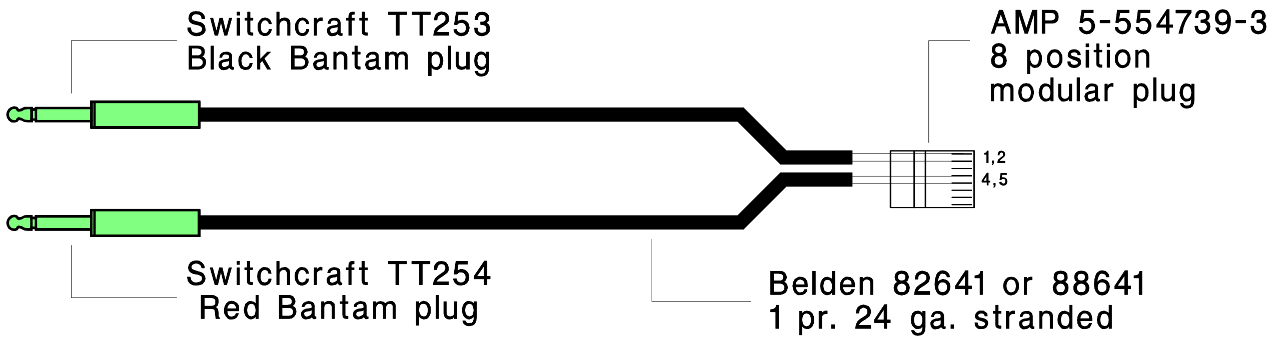


Fig. 8(a) - Test Harness Applications
Testing Toward CSU/DSU

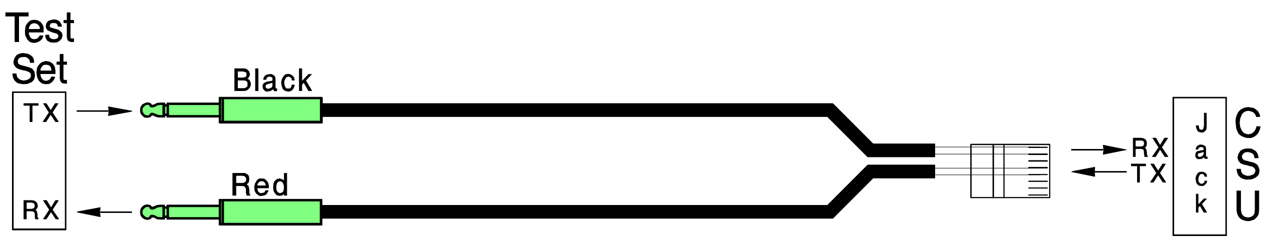
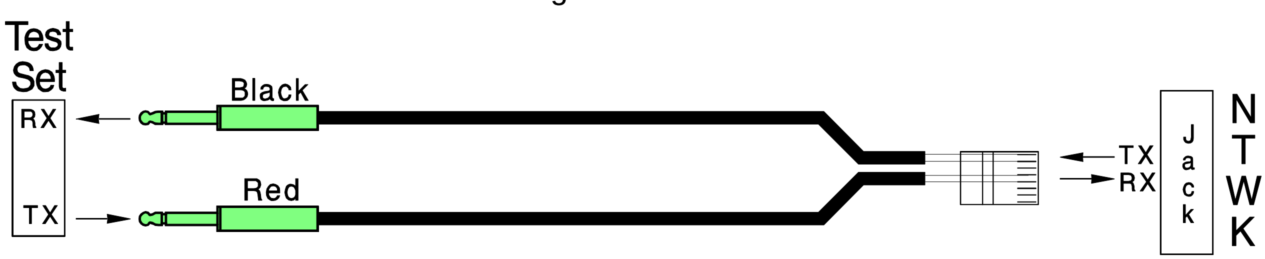
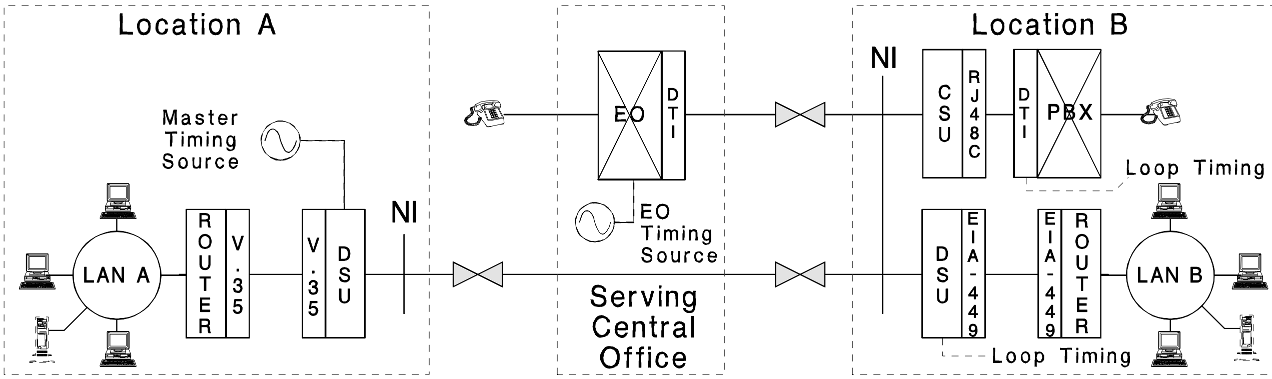


Fig. 8(b) - Test Harness Applications
Testing Toward network



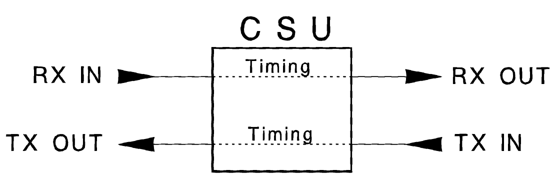
Except where the PBX is timed from a clock traceable to a Stratum 1 clock, the end office (EO) always is used as the master timing source for the PBX. Therefore, the PBX must be set to obtain timing from the network and return the timing in its transmitted signal (again, loop timing). If the PBX is timed from a clock that is traceable to a Stratum 1 clock, then the PBX and EO can be operated plesiochronously with no significant slip penalty under normal conditions.

Fig. 9
Timing Sources



A CSU (for example, as shown in Fig. 9) provides a DS1 signal on both the network and user side and normally is transparent to timing and does not have timing options. Data is passed through to the Transmit Out port at the data rate appearing at the Transmit In port. Similarly, data is passed through to the Receive Out port at the rate appearing at the Receive In port. See Fig. 10.

Fig. 10
CSU Timing



When a test set is connected at the end office or customer's premises, similar care must be taken to set its timing mode. The same considerations discussed above apply. If the network is the normal timing source and the test set temporarily replaces the network, the test set must be set for internal timing, that is, provide a timing source for downstream devices. If the test set faces the network, the test set must be set for loop-timing.

7. Signal Power Adjustment

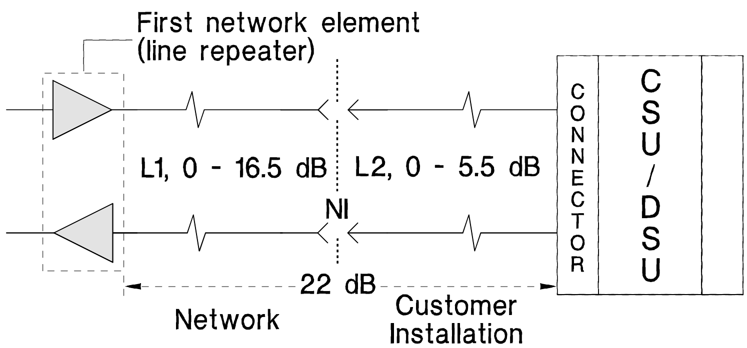
Of particular interest in the CSU and DSU is the signal output power adjustment. Signal power is adjusted by a Line Build-Out (LBO) to one of at least three settings. The setting depends on the loss between the CSU and the nearest telco network element. The nearest network element usually is the line repeater closest to the customer but may be an HDSL remote terminal or other active device, such as a Smartjack.

FCC Part 68, par. 68.308(g)(2)(iii) requires that signals from a customer installation to the first network element be controlled to ±4 dB. This limitation is achieved by using an LBO with three output pulse options or settings of 0, 7.5 and 15 dB, which indicate the loss introduced by the LBO at 772 kHz. The LBO has a shaped response to simulate twisted pair cable and is not a simple resistive attenuator.

One of the three settings is selected depending on the cable loss at 772 kHz between the network interface and the first network element. The setting must also take into account the loss in the customer wiring between the network interface and the CSU or DSU. See Fig. 13. ANSI T1.403

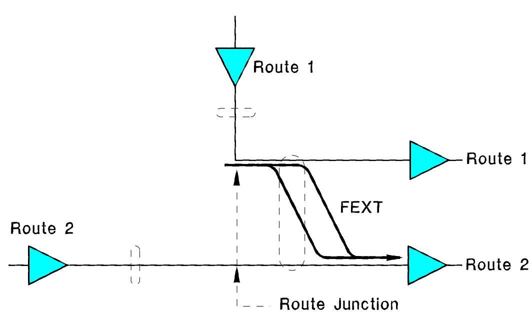
provides for a total of 22 dB loss between the first network element and the CSU or DSU. Of this total, up to 16.5 dB of loss are allocated to the segment between the network interface and the first network element. This loss is called L1 in Fig. 11. Therefore, the public network segment (between the network interface and the first network element) must be designed for no more than 16.5 dB of loss if it to conform to industry standards. Up to 5.5 dB of loss are allocated to the segment between the network interface and the CSU/DSU. This loss is called L2.

Fig. 11
Loss Allocation for Determining LBO Setting



The LBO is necessary to ensure that the signal levels arriving at the first network element are within a certain range with respect to signals from other customers or other network elements. This is especially important when the first network element is a line repeater and that repeater location serves both intermediate span line sections as well as end sections to a number of different customer locations. The points at which different cables serving the different spans merge are called route junctions. If a repeater is not located at the route junction, which frequently is the case, incoming signals are at different levels, potentially leading to Far-End Crosstalk, or FEXT. See Fig. 12. Route junctions require special design considerations to control FEXT.

Fig. 12
Far-End Crosstalk at Route Junctions



According to ANSI T1.403, the maximum allowable level difference at a line repeater location is 7.5 dB in most situations.[4] As required in FCC Part 68, the CSU LBO can be set in 7.5 dB steps, thus ensuring the CSU transmit level can be adjusted to meet both the FCC ±4 dB and the ANSI 7.5 dB level difference requirements for most situations.

The loss between the first network element and the network interface must be provided to the customer by the telco. The customer must know the loss between the network interface and the CSU/DSU. Then, the LBO is set such that the sum of L1, L2 and the LBO is between 15 and 22.5 dB, or

$$15 \text{ dB} \leq L1 + L2 + LBO \leq 22.5 \text{ dB}$$

When the network cable loss is known, and the loss in the customer wiring (L2) is negligible, Table 2 can be used to set the LBO.

[4] In modern and well maintained plant, the difference may be increased to 10 dB without line degradation.

Table 2
Pulse Option Settings Where Customer Wiring Loss is Negligible

Network Cable Loss (L1) @ 772 kHz	***Approximate Cable Length***	***FCC Output Pulse Option***	***LBO Loss @ 772 kHz***
15 to 22 dB	2000 to 3000 ft	A	0 dB
7.5 to 15 dB	1000 to 2000 ft	B	7.5 dB
0 to 7.5 dB	0 to 1000 ft	C	15 dB

Fig. 13
Signal Level Control

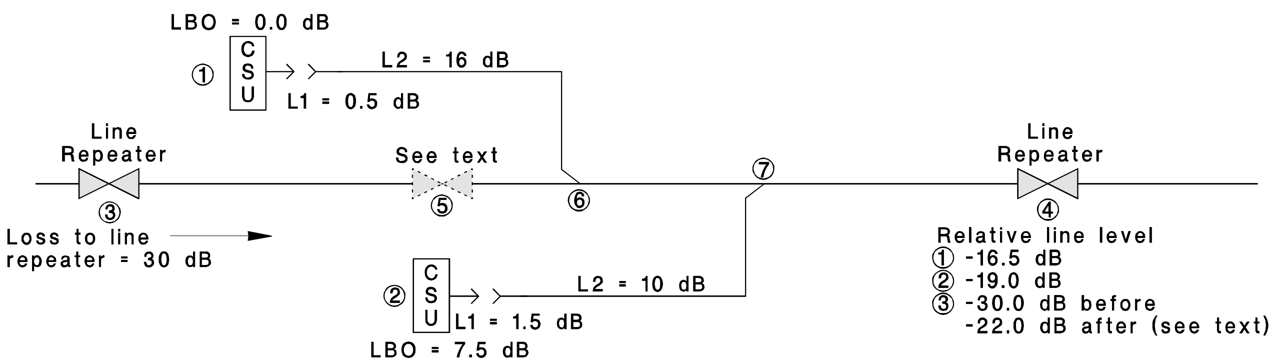


Fig. 13 shows a situation commonly encountered in the field when an existing interoffice repeatered T1-carrier route is later used for customer DS1 service. Locations ⟧ and ‖ in Fig. 13 are new customer service points. Locations ‖ and   are existing line repeater locations. The point at which the distribution cables from ⟧ and ‖ intersect the feeder at ~ and ~ are called route junctions. The LBOs are to be set as shown to meet ANSI requirements at . However, the level from the line repeater at ‖ is too low and will lead to FEXT at . This can be remedied by placing a line repeater in each route at ~ and ~. Alternately, a line repeater may be placed at ~ as shown dotted. The loss from ~ to   should be between 15 and 22 dB at 772 kHz to eliminate problems from FEXT. Placing the line repeater at ~ with loss = 22 dB to   gives a relative level of -22 dB at . It is apparent from this situation that all routes end up being treated as end-sections. Repeatered T1-carrier span line design and the special design considerations at route junctions are beyond the scope of this note; see reference by Reeve.

The foregoing applies only if the DS1 service is delivered by the telco directly through a repeatered T1-carrier span line and the first network element is a line repeater. Instead, the telco may deliver the service through a multiplexer, central office repeater or other active device (such as an HDSL remote terminal) on the customer’s premises with a corresponding network cable loss (L1) of 0 dB. Each of these devices expect a nominal ±3 v-p signal, which corresponds to an LBO setting of 0 dB. However, using the above equation results in an LBO setting of 15 dB. Therefore, in this case, it is necessary for the telco to advise the customer of the actual LBO setting (option A, or 0 dB) rather than network cable loss.

The equipment noted above is compatible with the DSX-1 signal levels, and the expected input level to the DSX is 0.0 dBdsx. Some CSUs, in addition to the three LBO settings discussed above, have DSX equalizer settings to compensate for the cable length between the CSU and the point at which a DSX compatible signal level is required. Typical equalizers have five settings, for example, 0 to 133 ft, 133 to 266 ft, 266 to 399 ft, 399 to 533, and 533 to 655 ft. These distances apply to AT&T type ABAM, 22 AWG, shielded twisted pair cables with 100 ohm characteristic impedance. The equalizer settings must be adjusted for the actual cable used, if different.

When testing signal levels at the output of a CSU/DSU, the LBO setting must be taken into account. For example, if the LBO is set to Option C (15.0 dB), the test set will read a signal level of -15.0 dBdsx. Similarly, if a test set temporarily replaces a CSU/DSU, the LBO in the test set (if available) must be set to correspond to the CSU/DSU LBO setting.

8. Past FCC Requirements and Other Considerations

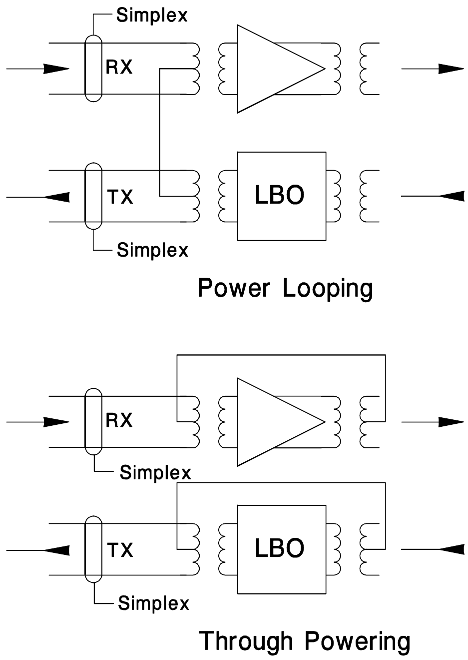
FCC Part 68, par. 68.318 originally required that customer equipment provide signal continuity by either meeting a minimum pulse density requirement (12.5%) or, under low density signal conditions, by transmitting a keep-alive signal from the customer equipment. The keep-alive signal could be any of the following:

- Framed all-ones signal
- Unframed all-ones signal
- Signal produced by regenerating the received network signal and connecting it to the transmit port through a loopback circuit

The FCC also required that the line power to operate the equipment that provided the signal continuity be derived from the network. This requirement disappeared completely on December 1, 1992, and the minimum pulse density, keep-alive signal, and network power are no longer required.

Even though the line power between the network and network interface is no longer required, line power still should be used to provide sealing current. The sealing current is necessary to keep outside plant cable splices clear of oxide films that can introduce high transmission losses or noise. It is not required that customer equipment use the current for powering purposes. All modern CSUs and DSUs provide dc continuity between the transmit and receive simplex circuits, so the network line power is looped back, as it should be. Fig. 14 shows two powering schemes - power looping and through powering. The power looping is the most common. In some CSUs, the power looping dc continuity is provided by an option setting. The RJ48X jack (shown in Fig. 5) provides dc continuity when the customer equipment is unplugged.

Fig. 14
CSU/DSU Simplex Powering



9. The Option Problem

All CSUs and DSUs have option settings, either through hardware dipswitches or jumpers or software switches. While there are differences in terminology, the basic functions and features are the same. This section describes the most common features not already discussed and provides guidance on how to set them.

Loopback keep-alive/AIS keep-alive - This option selects the type of signal sent out to the network by the CSU/DSU upon loss of signal on the DTE side. The loopback option simply returns the signal at the network receive port to the transmit port. The AIS option inserts an unframed all-ones signal on the network transmit port. Either method is acceptable, although the serving telco may specify one or the other for their own network management purposes. See Fig. 15.

ESF/D4 framing - Many CSUs are capable of setting the framing format to ESF or D4 on both the network and user side. When set differently, format conversion is possible. For example, D4 on the network side could be converted to ESF on the user side. If the framing format is not set correctly, the device will not work. The D4 format also is known as both D3/D4 and Superframe Format, or SF. DSUs only set the framing on the network side.

B8ZS/AMI line code - Many CSUs are capable of setting the line code to B8ZS or AMI on both the network and user side, giving the possibility of line code conversion. If the transmitter is optioned B8ZS and the receiver optioned AMI, errors and bipolar violations will be reported, so it is important that both ends be optioned the same. DSUs only set the line code on the network side.

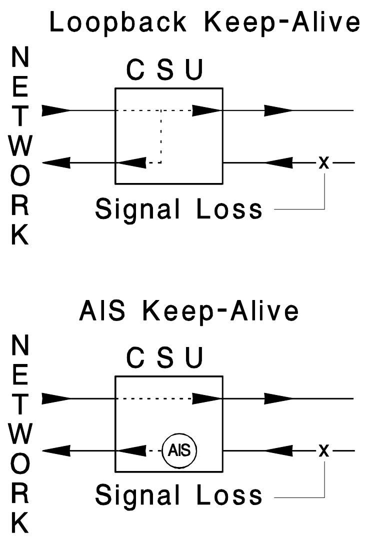
Address - The address option normally applies to shelf mounted CSU/DSUs used in network management systems. However, even if an addressable CSU/DSU is not used in this system, it still should be assigned a unique address.

Performance report messages - This feature applies only to CSUs that use ESF. There are two common performance report formats, which are carried in the Facility Data Link of the ESF. These are known as the TR54016 format (after the AT&T technical reference) and the ANSI T1.403 format. The ANSI T1.403 format is preferred. Parameters from this format can be translated into the TR54016 format at the receive end if necessary (but the reverse is not true).

Equalizer on DTE side - Equalizer settings are important to maintaining the proper pulse levels at DSX panels or equipment that operates at DSX levels, such as multiplexers and fiber optic terminals. A thorough discussion of the DSX is given in another application note.[5]

[5] See Application Note No. 2, *DSX Applications in Small Central Offices.*

Fig. 15
Keep-Alive Options



TR62411 enforcement/Pre-1990 FCC Part 68 density - This feature also is called pulse stuffing. In one setting, it ensures that the bit stream sent to the network complies with TR62411, which allows no more than 15 consecutive zeros and requires at least N pulses in 8(N+1) bit positions. This is the preferred setting when the AMI line code is used. In the other setting, this feature only enforces the old FCC requirement for no more than 80 bit positions with no pulses. In modern CSU/DSUs, the other position provides no pulse density enforcement whatsoever. When the CSU is set for the B8ZS line code, this option setting normally does not matter because B8ZS provides the required pulse density.

Sealing current/span power dc continuity - In modern CSUs, there is no option setting for sealing current because a dc short is provided between the transmit and receive simplex circuits. Some CSUs have the option of providing sealing current to the network or providing the dc short on the simplex circuits. The latter is most often used. In older CSUs, the option may be labeled Through/Looped Power, in which case the Through setting provides a dc path from the network to the DTE side on the simplex circuits. The Looped Power setting provides a dc short between the transmit and receive simplex circuits on the network side.

10. References

ANSI T1.403-1995, American National Standard for Telecommunications - Network-to-Customer Installation - DS1 Metallic Interface.
ATIS Report No. 5, Committee T1 - Telecommunications, A Technical Report on Carrier to Customer Installation Interface Connector Wiring Configuration Catalog, April 1994.
Reeve, W.D., Subscriber Loop Signaling and Transmission Handbook: Digital, IEEE Press, 1995.
Reeve, W.D., Application Note No. 2, DSX Applications in Small Central Offices.
Reeve, W.D., Application Note No. 4, Testing DS1 Services.

Availability: ANSI standards are available directly from the American National Standards Institute at 1+212-642-4900. IEEE Press books are available from IEEE Service Center at 1+800-678-IEEE. ATIS reports are available from the Alliance for Telecommunication Industry Solutions at 1+202-434-8845. See below for availability of other application notes.

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